Thermal Management for Pentium® Pro Processor-Based PCs

June 1996

Intel Corporation
Reseller Products Division

The Boxed Pentium® Pro processor may contain design defects or errors known as errata. Current characterized errata are available on request.

Introduction

This document is written for professional system integrators building PCs from industry accepted motherboards, chassis, and peripherals. It provides information and recommendations for thermal management in systems using the following Intel processors:

180 and 200 MHz Boxed Pentium® Pro processors

It is assumed that the reader has a general knowledge of and experience with PC operation, integration, and thermal management. Integrators who follow the recommendations presented here can provide their customers with more reliable PCs and will see fewer customers returning with problems. (The term “Boxed Pentium Pro processors” refers to processors packaged for use by system integrators.)

Thermal Management

Systems using Pentium Pro processors *all require thermal management*. The term “thermal management” refers to two major elements: a heatsink properly mounted to the processor, and effective airflow through the system chassis. The ultimate goal of thermal management is to keep the processor at or below its maximum operating temperature. For Pentium Pro processors and their future OverDrive® processor upgrades, the maximum operating temperature is 85°C, measured on the top of the processor package case, over the processor die.

Proper thermal management is achieved when heat is transferred from the processor to the system air, and the warm air is vented out of the system. Boxed Pentium Pro processors are shipped with a high-quality fan heatsink, which can effectively transfer processor heat to the system air. It is the responsibility of the system integrator to properly install the fan heatsink and ensure adequate system airflow.

This document makes recommendations for installing the fan heatsink, and achieving good system airflow. It also provides a procedure for determining the effectiveness of a system’s thermal management solution.

Integrated Fan Heatsink

Boxed Pentium processors are shipped with a fan heatsink, clip, fan cable, and small quantity of thermal grease. These items should be used following the directions contained within the Boxed Pentium Pro processor manual. When properly installed, the fan heatsink and processor assembly appears as shown in Figure 1.

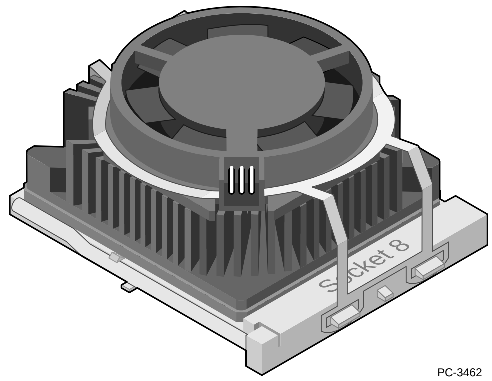

Figure 1. Boxed Pentium Pro Processor with Fan Heatsink and Clip

A small amount of thermal grease mates the fan heatsink to the processor. This thermal grease aids in heat transfer, and absorbs vibration. The clip tightly holds the fan heatsink to the processor, by connecting to mounting tabs on the socket. The fan cable provides power to the fan, by connecting to a disk drive power connector.

The fan is a high-quality ball bearing fan that provides a good local air stream. This local air stream transfers heat from the heatsink to the air inside the system. Moving heat to the system air is half the task. Sufficient system airflow is also needed in order to exhaust the air. Without a steady stream of air through the system, the fan heatsink will recirculate warm air, and therefore may not cool the processor enough.

System Airflow

System airflow is determined by chassis design, size and location of chassis air intake and exhaust vents, power supply fan capacity and venting, location of the processor socket, and placement of add-in cards and cables. System integrators must ensure airflow through the system to allow the fan heatsink to work effectively. Proper attention to airflow when selecting subassemblies and building PCs is important for good thermal management and reliable system operation.

Two basic motherboard-chassis-power supply form factors are used by integrators: the Baby AT form factor, and the more recent ATX form factor.

In systems using Baby AT components, airflow is usually from front to back. Air enters the chassis from vents at the front and is drawn through the chassis by the power supply fan. The power supply fan exhausts the air through the back of the chassis. Figure 2 and Figure 3 show the airflow through Baby AT systems.

The ATX form factor is a recent innovation to PC form factors. The ATX form factor simplifies assembly and upgrading of PCs, while improving the consistency of airflow to the processor. In regards to thermal management, ATX components differ from Baby AT components in that ATX

power supplies draw air *in* to the chassis rather than venting out system air. Also, on an ATX motherboard, the processor socket is located close to the power supply, rather than to the front panel of the chassis. Because of these component differences, the airflow in ATX chassis usually flows from the back of the chassis, directly across the processor, and out of the front, side, and rear vents of the chassis. Figure 4 shows proper airflow through an ATX system.

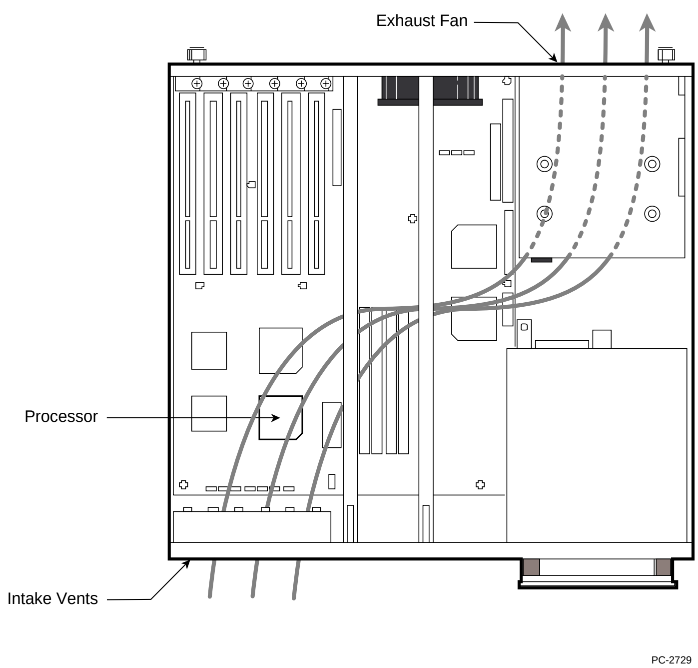

Figure 2. System Airflow through Baby AT Desktop Chassis (Top View)

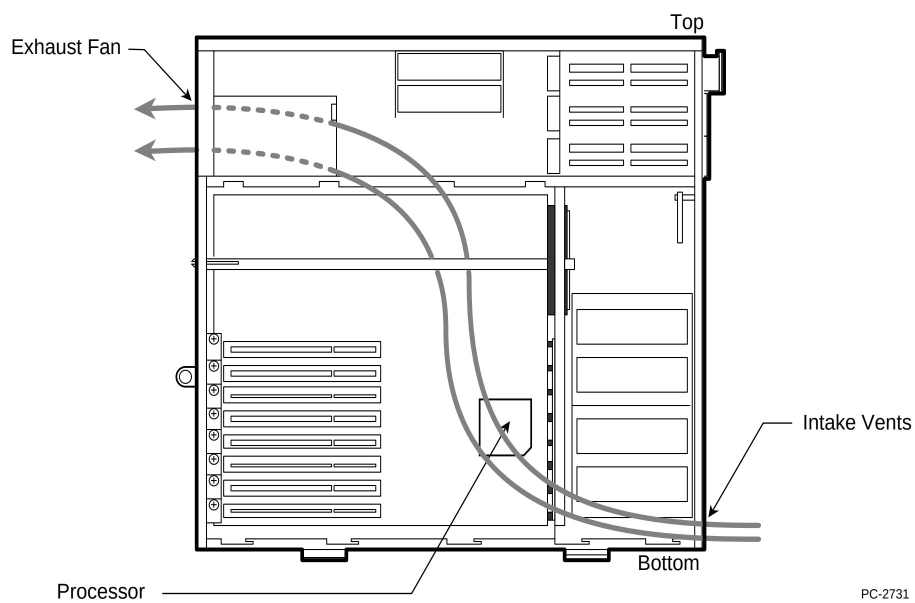

Figure 3. System Airflow through Baby AT Tower Chassis (Side View)

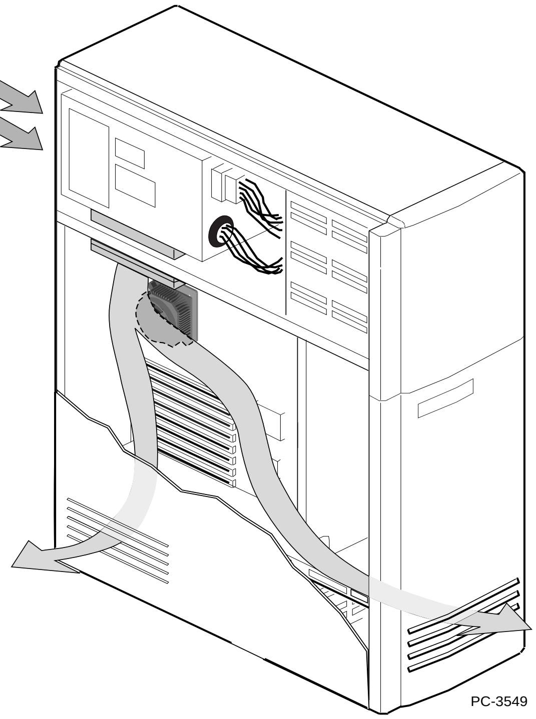

Figure 4. System Airflow through ATX Tower Chassis (side view)

The following is a list of guidelines to be used when integrating a system. Specific mention of Baby AT and ATX components is made where necessary.

- **Chassis vents must be functional and not excessive in quantity:** Integrators should be careful not to select chassis that contain cosmetic vents only. Cosmetic vents are designed to look like they allow air into the chassis but no air (or little air) actually enters. Chassis with excessive air vents should also be avoided. For example, if a Baby AT chassis has large air vents on all sides, most air enters near the power supply and then immediately exits through the power supply or nearby vents. Very little air flows over the processor and other components.

- **Vents must be properly located:** Systems must have properly located intake and exhaust vents. The best location for air intakes allows air to enter the chassis and directly flow over the processor. Exhaust vents should be situated so that air flows on a path through the system, over various components, before exiting. Specific location of vents depends upon the type of chassis. For most desktop Baby AT systems, the processor is located near the front, and thus intake vents on the front panel work best. For Baby AT tower systems, intake vents on the bottom of the front panel work best. For ATX systems, exhaust vents should be located both in the bottom front and bottom rear of the chassis.

- **Power Supply Directional Air Flow:** It is important to choose a power supply that has a fan which draws air in the proper direction. For Baby AT systems, the power supply fan needs to act as an exhaust fan, venting system air outside the chassis. For ATX systems, the

power supply needs to act as an intake fan, drawing air into the system. Some power supplies have markings noting airflow direction. Ensure the proper power supply is used based upon the system form factor.

- **Power Supply Fan Strength:** PC power supplies contain a fan. Depending upon the type of power supply, the fan either draws air into or out of the chassis. If intake and exhaust vents are properly located, the power supply fan can draw enough air for most systems. If the air intake or exhaust is limited or restricted, however, the fan will not move much air. For some chassis where the processor is running too warm, changing to a power supply with a stronger fan can greatly improve the airflow.

- **System Fan - Should It be Used?:** Some chassis may contain a system fan (in addition to the power supply fan) to facilitate airflow. A system fan is typically used with passive heatsinks. With fan heatsinks, a system fan can have mixed results. In some situations, a system fan improves system cooling, however, sometimes a system fan recirculates warm chassis air, thereby reducing the thermal performance of the fan heatsink. When using processors with fan heatsinks, rather than adding a system fan, it is generally a better solution to change to a power supply with a more powerful fan. Thermal testing both with a system fan and without the fan will reveal which configuration is best for a specific chassis.

- **System Fan Directional Airflow:** When using a system fan, ensure that it draws air in the same direction as the overall system airflow. For example, a system fan in a Baby AT system might act as an intake fan, pulling in additional air from the front chassis vents. A system fan in an ATX system, however, might act as an exhaust fan, pulling air from within the system out through the rear or front chassis vents

- **Protect Against Hot Spots**: A system may have a strong air flow, but still contain "hot spots." Hot spots are areas within the chassis that are significantly warmer than the rest of the chassis air. Such areas can be created by improper positioning of the exhaust fan, adapter cards, cables, or chassis brackets and subassemblies blocking the airflow within the system. To avoid hot spots, remember that hot air rises, and place exhaust fans accordingly, reposition full-length adapter cards, or use half-length cards, re-route and tie back cables, and ensure space around and over the processor.

Thermal Testing (System Checkout)

Differences in motherboards, power supplies, and chassis all affect the operating temperature of processors. Thermal testing is highly recommended when choosing a new supplier for motherboards or chassis, or when starting to use new products. Thermal testing can show integrators if a specific chassis-power supply-motherboard configuration provides adequate airflow for the Boxed Pentium Pro processors and their future OverDrive processors.

An easy method for performing thermal testing is to attach a thermal indicator label to the bottom of the processor before placing the processor in its socket. The processor is installed and the chassis cover is attached. The system is powered up and exercised for 1 hour. The system is powered down, the cover is removed, and the system is allowed to cool. The processor is then removed from its socket and the thermal indicator label is checked. The label indicates the

highest temperature range the processor reached during operation. Along with the room temperature, the thermal label temperature can be used in a calculation to verify the maximum operating temperature of the system (this calculation is described later.)

Figure 5 shows a thermal indicator label. Each label has several temperature ranges that change from white to red at different temperature levels. Once a level has changed color, it stays that color. This feature allows the labels to record the maximum temperature reached during testing.

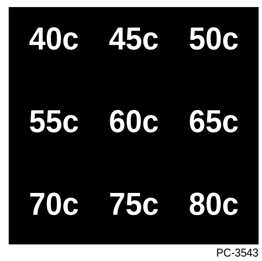

Figure 5. Thermal Indicator Label

In addition to the thermal labels, the equipment required for testing includes:

- A thermometer (to measure room temperature)
- The DOS EDIT.EXE program on a system disk (disk boots to DOS.) EDIT.EXE must be from DOS 5.xx, or 6.xx, not from another operating system.

The procedure for thermal testing is as follows:

Note: *If you are testing a system with a variable-speed system fan, you must run the test at the maximum operating room temperature you have specified for the system.*

1. To ensure maximum power consumption during the test, you must disable the system's automatic powerdown modes or "green features." These features are controlled either within the system BIOS or by operating system drivers.

2. Make sure that the processor is cool enough before applying or removing a label. *If the system is powered on at the start of the test, wait at least 15 minutes after turning off power and removing the chassis cover.*

3. Place a thermal label on the bottom of the processor package. The Pentium Pro processor package contains two silicon die, the label must be placed over the CPU rather than over the cache. The CPU is on the side of the package with the extra (staggered) pins. Figure 6 shows correct placement of the label on the processor.

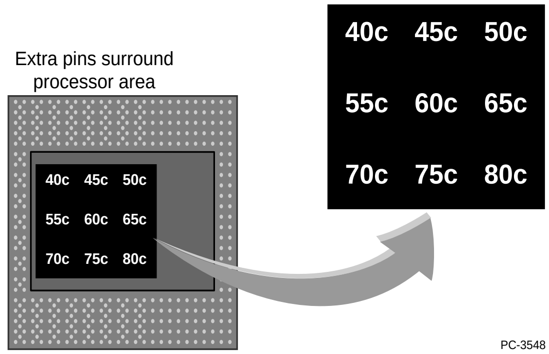

Figure 6. Pentium Pro Processor with Thermal Indicator Label

4. Install the Boxed Pentium Pro processor and connect the fan heatsink power cable. (See Hint 1 to determine which speed processor should be tested.)

5. If you disconnected cables or removed boards to install the processor, replace them now. Quickly power up and power down the system to make sure the fan rotates. Check the fan heatsink power connections if the fan is not rotating.

6. Attach the chassis cover and replace cover screws.

7. If the system boots to DOS, go to step 8. If the system doesn't boot DOS, for example it boots Windows 95* or OS/2*, insert the bootable DOS disk with EDIT.EXE into drive A.

8. Power up the PC. If the system has been assembled properly, and the processor is properly installed and seated, the system boots to DOS.

9. Invoke DOS EDIT and select the FILE pull-down menu (ALT + F). Leaving the menu pulled down constantly exercises the processor, causing the processor to rapidly heat up.

10. Allow the menu to remain pulled down for 1 hour. This allows the entire system to heat up and stabilize. Record the room temperature at the end of the 1 hour period.

11. After recording the room temperature, power the system down. Remove the chassis cover. *Allow the system to cool at least 15 minutes.*

12. Remove the processor and turn it over to examine the thermal label.

13. Record the thermal label's lowest temperature range that remained white. Remove the label when testing is complete. Labels cannot be used again.

Proceed to the next section to verify the maximum operating temperature for the system.

Testing Hints

Use the following hints to reduce the need for additional thermal testing.

1. When testing a system that supports more than one speed of processor, test with the motherboard configured for the processor that generates the most heat (dissipates the most power). By testing the warmest processor supported, the processors that generate less heat do not explicitly need to be tested with the same motherboard and chassis configuration.

   Lower speed processors usually generate less heat than higher speed processors. However, there are exceptions when processors are based on different silicon technology. To ensure selection of the appropriate processor, refer to Table 1 for power dissipation numbers for Pentium Pro processors.

   For example, if a motherboard supports speeds up to 200 MHz, the system should be tested using the 200 MHz part, as this part dissipates more power than a 180 MHz part.

Pentium Pro Processor Speed	**Power Dissipation**
180 MHz	31.7 W
200 MHz	35 W

Table 1. Pentium Pro Processor Speed vs. Power Dissipation

2. Thermal checkout with a new motherboard is not necessary if all of the following conditions are met:
   - The new motherboard is used with a previously tested chassis that worked with a similar motherboard. The previous test showed the configuration to provide adequate airflow.
   - The processor is located in approximately the same place on both motherboards.
   - A processor with the same or lower power dissipation will be used on the new motherboard.

3. Most systems are upgraded (additional RAM, adapter cards, drives, etc.) sometime during their life. Integrators should test systems with some expansion cards installed in order to simulate a system that has been upgraded. A thermal management solution that works well in a system that is heavily loaded does not need to be retested for lightly loaded configurations.

Calculation to Verify a System's Thermal Management Solution

This section explains how to determine whether a *system* meets the maximum operating temperature intended while keeping *the processor* within its maximum operating range. The result of this process shows whether or not system airflow needs to be improved or the system maximum operating temperature needs to be revised in order to produce a more reliable system. (An example is provided at the end of this section.)

The first step is to select a maximum operating room temperature for the system. A common value for systems where air conditioning is *not* available is 40°C. A common value for systems where air conditioning *is* available is 35°C. Choose a value that is right for your customer. Write this value on line A below.

Write the room temperature recorded after testing on line B below. Subtract line B from line A and write the result on line C. This difference compensates for the fact that the test was likely conducted in a room that is cooler than the system's maximum operating temperature.

(Appendix A contains a table for converting between Fahrenheit and Celsius scales.)

A.		_ _ _ _ _	(Maximum operating temperature, typically 35°C or 40°C)
B.	-	________	room temperature °C at end of test
C.		_ _ _ _ _	

Write the temperature recorded from the indicator label (lowest temperature range that remained white) on line D below. Copy the number from line C to line E below. Add line D and line E and write the sum on line F. This number represents the highest temperature for the *bottom* of the processor when the system is used at its specified maximum operating room temperature. There is one more step.

Since the top of the processor gets warmer than the bottom, we need to take that difference into account. Add 5°C to the value on line F and write the sum on line G.

D.		_ _ _ _ _	temperature from label
E.	+	_______	
F.		_ _ _ _ _	
	+	5°C	top to bottom difference
G.		_ _ _ _ _	Calculated processor case temperature

The value on line G represents the package case temperature of the processor when the system is operated in its warmest environment. Processors should not be run at temperatures higher than their maximum specified operating temperature or failures may occur. (This maximum temperature for a Pentium Pro processor is 85°C.) If line G reveals that the *processor* reached a temperature higher than its maximum operating range, then action is required. Either the system airflow must be significantly improved, or the *system's* maximum operating room temperature must be revised lower.

The specification for the Pentium Pro processor states the maximum case temperature to be 85°C. Therefore, if the number on line G is less than or equal to 85°C, the system will keep the Pentium processor within specification, even if the system is operated in its warmest environment. Note that future OverDrive processors that can be installed in the socket have the same thermal characteristics as the Pentium Pro processor. No additional headroom will be needed to support these OverDrive processors.

To summarize:

If the value on line G is greater than 85°C, there are two options:

1. Improve system airflow to bring the processor's temperature down (follow the recommendations made earlier). Then retest the system using another thermal label.
2. Choose a lower maximum operating room temperature for the system. Bear in mind the customer and the system's typical environment.

After implementing either option, you must re-calculate the thermal calculation to verify the solution.

Example thermal calculations are provided below:

Example 1

This example assumes that a system with a 200 MHz Pentium Pro processor is being tested. The intended maximum room temperature for the system is 40°C. The room temperature during the test is 25°C. The first six temperature ranges (40°C, 45°C, 50°C, 55°C, 60°C, 65°C) on the thermal indicator label change color but the 70°C temperature range stays white.

A)	40	°C	intended maximum room temperature for system
B)	- 25	°C	actual room temperature during testing
C)	15	°C	difference
D)	70	°C	maximum processor temperature during testing (lowest temperature range remaining white)
E)	+ 15	°C	difference from first calculation (step C)
F)	85	°C	maximum temperature on bottom of processor
	+5	°C	difference between bottom and top of processor
G)	90	°C	maximum processor temperature in system's maximum room temperature

This system does *not* provide a good thermal management solution. If the system were run in its maximum operating room temperature of 40°C, the processor would run above its temperature specification (90°C is greater than 85°C.) To improve the thermal situation, one of two options must be performed; 1) improve the airflow through the system, or 2) lower the system's maximum operating room temperature from 40°C to 35°C, thereby requiring the system to be run in an air-conditioned environment.

Example 2

This example assumes that a system with a 200 MHz Pentium Pro processor is being tested. The intended maximum room temperature for the system is 40°C. The room temperature during the test is 25°C. The first three temperature ranges (40°C, 45°C, and 50°C) on the thermal indicator label change color but the 55°C temperature range stays white.

A)	40	°C	intended maximum room temperature for system
B)	- 25	°C	actual room temperature during testing
C)	15	°C	difference
D)	55	°C	maximum processor temperature during testing (lowest temperature range remaining white)
E)	+ 15	°C	difference from first calculation (step C)
F)	70	°C	maximum temperature on bottom of processor
	+5	°C	difference between bottom and top of processor
G)	75	°C	maximum processor temperature in system's maximum room temperature

This system does provide good thermal management for the Pentium Pro processor and its future OverDrive processor upgrade.

Appendix A

The following table is provided to help convert degrees Fahrenheit to degrees Celsius.

°F	°C	
59	15	
61	16	
62.5	17	
64.5	18	
66	19	
68	20	
70	21	
71.5	22	typical office room temperature
73.5	23	
75	24	
77	25	
79	26	
80.5	27	
82.5	28	
84	29	
86	30	
88	31	
89.5	32	
91.5	33	
93	34	
95	35	Typical maximum operating room temperature for a system in an air-conditioned environment.
97	36	
98.5	37	
100.5	38	
102	39	
104	40	Typical maximum operating room temperature for a system in a non-air-conditioned environment.
105.8	41	
107.6	42	
109.4	43	
111.2	44	
113	45	
114.8	46	
116.6	47	

°F	°C
118.4	48
120.2	49
122	50
123.8	51
125.6	52
127.4	53
129.2	54
131	55
132.8	56
134.6	57
136.4	58
138.2	59
140	60
141.8	61
143.6	62
145.4	63
147.2	64
149	65
150.8	66
152.6	67
154.4	68
156.2	69
158	70
159.8	71
161.6	72
163.4	73
165.2	74
167	75
168.8	76
170.6	77
172.4	78
174.2	79
176	80